Charm and bottom production in two-photon collisions with OPAL[1]

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Abstract. A preliminary update of the previous OPAL measurement of the inclusive production of $D^{*\pm}$ mesons in anti-tagged photon-photon collisions is presented together with the first preliminary OPAL measurement of bottom production in photon-photon collisions.

INTRODUCTION

Heavy quark production in photon-photon collisions reveals the structure of a fundamental gauge boson, the photon. It can be calculated in perturbative QCD and is sensitive to the quark and gluon content of the photon. At LEP2 energies the two main processes, direct and single-resolved, have approximately the same contribution, while the double-resolved contribution is negligible.

Charm production in photon-photon collisions can be cleanly tagged e.g. by the full reconstruction of charged D^* mesons, while bottom production can be measured through a careful study of the various sources of final state leptons in hadronic two-photon events.

CHARM PRODUCTION

We present a preliminary update on the measurement of D^* production in anti-tagged photon-photon collisions [1]. The main change compared to the previous analysis is the inclusion of data collected by OPAL in 1999 at e^+e^- centre-of-mass energies $\sqrt{s_{ee}} = 192 - 202$ GeV, bringing the total integrated luminosity to 428 pb^{-1} in the centre-of-mass energy range $183 < \sqrt{s_{ee}} < 202$ GeV with a luminosity-weighted average energy of $\langle\sqrt{s_{ee}}\rangle = 193$ GeV.

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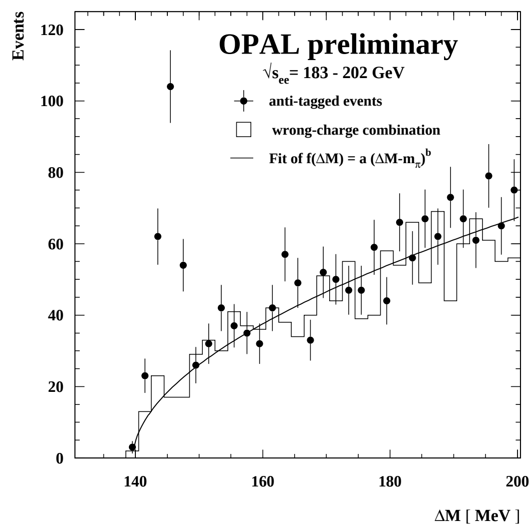


FIGURE 1. Mass difference $\Delta M \equiv M^{\rm cand}_{\rm D^*} - M^{\rm cand}_{\rm D^0}$ for the full sample. A clear peak is visible around $\Delta M \equiv M_{\rm D^*} - M_{\rm D^0} = 145.4$ MeV. The open histogram represents the wrong-charge sample which gives a good description of the combinatorial background. The result of a fit to the background is superimposed.

$\rm D^{*+}$ mesons are reconstructed in their decay to $\rm D^0\pi^+$, with the $\rm D^0$ observed in the two decay modes $\rm K^-\pi^+$ (3-prong) and $\rm K^-\pi^+\pi^-\pi^+$ (5-prong). The charge-conjugate decay chain is used for $\rm D^{*-}$ mesons. The distribution of the mass difference between the $\rm D^*$ and the $\rm D^0$, ΔM, for the combined data set is shown in Figure 1. Background is subtracted by fitting the function $f(\Delta M) = a\cdot(\Delta M - m_\pi)^b$, where a and b are free parameters and m_π is the pion mass, to the combined upper sideband of the signal and the wrong-charge distribution in the range 160.5 MeV $< \Delta M <$ 200.5 MeV. The result of the fit is in good agreement with the wrong-charge combination in the signal region. In total we observe 164.3 ± 14.9 (stat) $\rm D^*$ mesons.

According to the PYTHIA Monte Carlo program the $\rm D^*$ selection efficiencies for the transverse momentum and rapidity range of $p_{\rm T}^{\rm D^*} > 2$ GeV and $|\eta^{\rm D^*}| < 1.5$ are around $31-34\%$ for the 3-prong and $7-9\%$ for the 5-prong decay modes in single-resolved and direct events. The approximately 6% lower efficiency compared to the published analysis is due to additional electron rejection cuts which significantly improve the purity of the signal.

Two methods are used to determine the relative fraction of direct and single-resolved events in the data sample. One is based on $x_\gamma^{\rm min}$, defined in two-jet events using the cone algorithm as the minimum of $x_\gamma^\pm = \Sigma_{\rm jets}(E \pm p_z)/\Sigma_{\rm hadrons}(E \pm p_z)$, while the other uses the scaled $\rm D^*$ transverse momentum $x_{\rm T}^{\rm D^*} = 2p_{\rm T}^{\rm D^*}/W_{\rm vis}$, available in all events. The results of both methods are shown in Figure 2. The ratio of direct to single-resolved contributions in the dijet events determined by a fit to the $x_\gamma^{\rm min}$

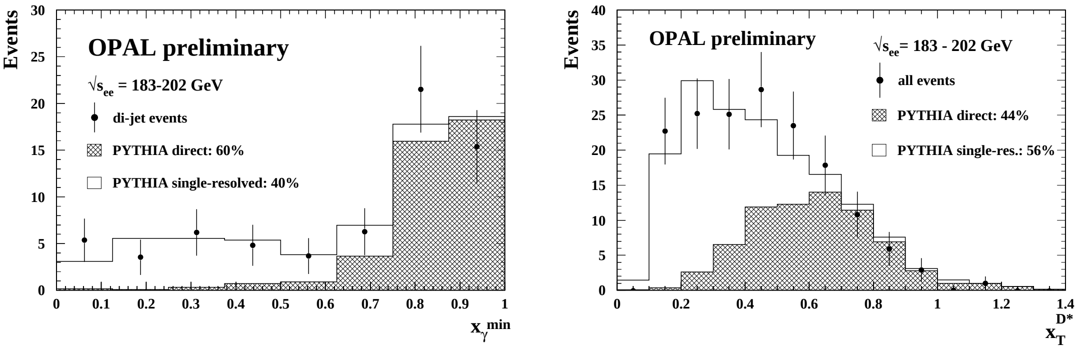


FIGURE 2. $x_\gamma^{\rm min}$ for dijet events (left) and $x_{\rm T}^{\rm D^*}$ for all events (right) in the signal region. The open area shows the fitted contribution from the single-resolved process, and the hatched area the one from the direct process.

distribution yields (60±8)% direct and (40±8)% single-resolved, while the fit to the $x_{\rm T}^{\rm D^*}$ distribution yields (44±6)% direct and (56±6)% single-resolved contributions, where all errors are statistical only. The requirement of two jets introduces a bias towards a larger direct component, therefore the $x_{\rm T}^{\rm D^*}$ method, where the full sample is used, is preferred.

In Figure 3 the combined differential cross-section $\mathrm{d}\sigma/\mathrm{d}p_{\rm T}^{\rm D^*}$ is compared to a next-to-leading order (NLO) calculation by Frixione et al. [2], where the matrix elements for massive charm quarks are used, and to an NLO calculation by Binnewies et al. [3], where charm is treated as a massless, active flavour in the photon parton distribution function. Despite the low transverse momenta studied, the massless calculation describes the measurement, while the massive calculation underestimates it in the region of small $p_{\rm T}^{\rm D^*}$. This is contrary to the expectation that the massive approach should be more appropriate at lower transverse momenta than the massless approach.

The integrated cross-section $\sigma_{\rm meas}$ of the anti-tagged process $\mathrm{e^+e^-} \to \mathrm{e^+e^-D^*}X$ in the directly observed kinematical region 2 GeV $< p_{\rm T}^{\rm D^*} <$ 12 GeV and $|\eta^{\rm D^*}| < 1.5$ is determined to be $\sigma_{\rm meas}^{\rm D^*} = 30.7 \pm 2.8(\mathrm{stat}) \pm 3.3(\mathrm{syst})$ pb. The extrapolation of this result to the full kinematic range using Monte Carlo simulations gives $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}}) = 1033 \pm 102\ (\mathrm{stat}) \pm 111\ (\mathrm{syst}) \pm 246\ (\mathrm{extr})$ pb for the total cross-section of the anti-tagged $\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}}$ process at $\langle\sqrt{s_{\rm ee}}\rangle = 193$ GeV. The first error is statistical, the second is systematic and the third is the extrapolation uncertainty, determined by varying the Monte Carlo parameters used in the extrapolation. The direct contribution is determined to be $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}})_{\rm dir} = 362 \pm 59\ (\mathrm{stat}) \pm 42\ (\mathrm{syst}) \pm 68\ (\mathrm{extr})$ pb while the single-resolved contribution is $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}})_{\rm res} = 671 \pm 110\ (\mathrm{stat}) \pm 77\ (\mathrm{syst}) \pm 178\ (\mathrm{extr})$ pb.

Figure 3 shows the total cross-section $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-c\bar{c}})$ compared to other measurements [4] and to the massive NLO calculation of [5]. Within the large band of uncertainties, the calculation is in good agreement with most measurements.

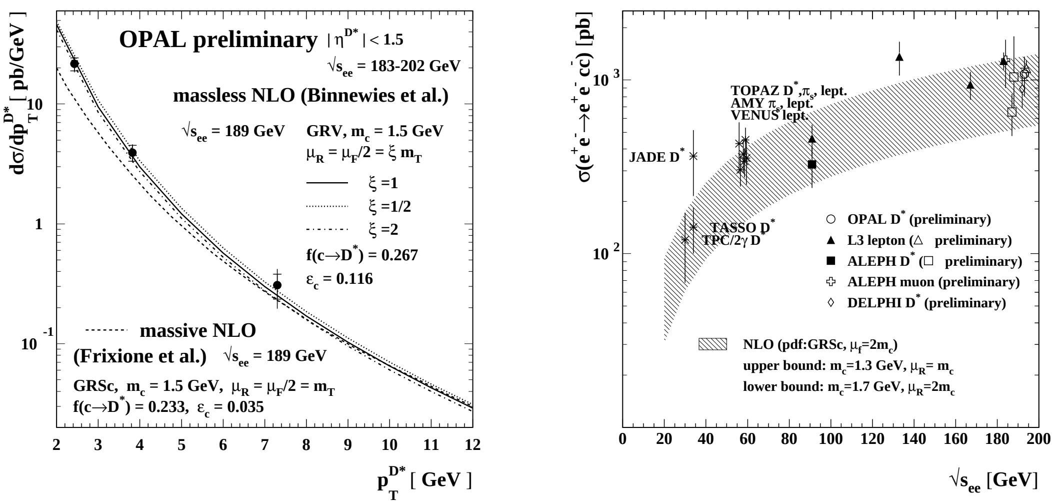


FIGURE 3. The differential D^* cross-section, $\mathrm{d}\sigma/\mathrm{d}p_{\mathrm{T}}^{\mathrm{D}^*}$, for the process $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-\mathrm{D}^*X$ in the range $|\eta^{\mathrm{D}^*}| < 1.5$, compared to an NLO calculation using the massless approach [3] and another one using the massive approach [2] (left) and the total cross-section for the process $\mathrm{e}^+\mathrm{e}^- \rightarrow \mathrm{e}^+\mathrm{e}^-\mathrm{c}\overline{\mathrm{c}}$ also compared to an NLO calculation [5] and other measurements [4] (right).

BOTTOM PRODUCTION

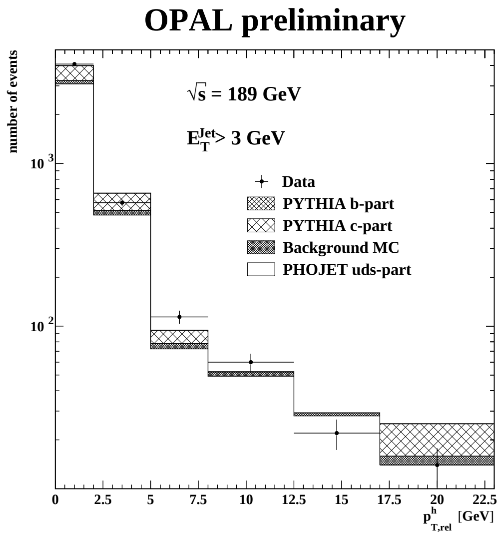
A new preliminary OPAL measurement of open bottom production in photon-photon collisions is presented using data collected at $\mathrm{e}^+\mathrm{e}^-$ centre-of-mass energies from $\sqrt{s_{\mathrm{ee}}} = 189$ to 202 GeV corresponding to a total integrated luminosity of about 371 pb^{-1}.

The selection of open beauty events proceeds in three steps. First, anti-tagged photon-photon events are selected. Within these events, muon candidates are reconstructed as a signature for semileptonic beauty decays. Finally, jets are reconstructed within the selected events, and the transverse momentum of the muon candidates with respect to the axis of the closest jet is computed.

An artificial neural network trained for muon identification [6] is used to enhance the purity of the muon sample. Events are selected if they contain exactly one muon candidate with a neural net output $\mathcal{N}_\mu$ larger than 0.65. The transverse momentum of the muons, $p_{\mathrm{T,rel}}^{\mu}$, is measured with respect to the axis of the closest jet reconstructed with the KTCLUS jet finding algorithm [7]. At least one jet with a transverse energy $E_{\mathrm{T}}^{\mathrm{jet}}$ with respect to the beam axis greater than 3 GeV and at least three tracks is required. After this final cut 444 events remain in this b-enriched sample.

Four contributions to the $p_{\mathrm{T,rel}}^{\mu}$ distribution have to be taken into account: hadronic photon-photon interactions with open b production, open c production, the remaining hadronic photon-photon interactions (labelled ‘uds’) and processes other than hadronic photon-photon interactions (labelled ‘BG’).

The number of b events is determined by a fit to the $p_{\mathrm{T,rel}}^{\mu}$ distribution after



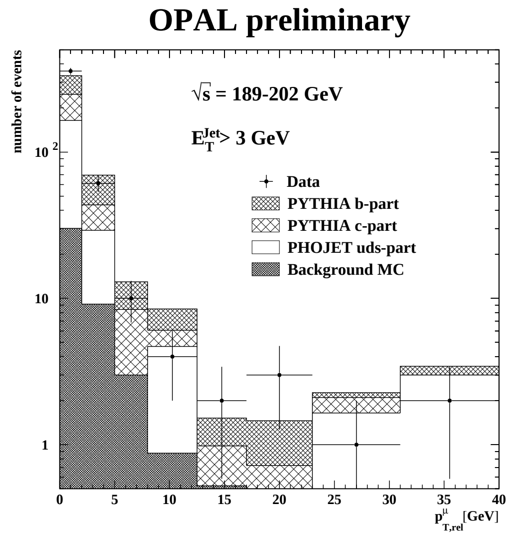


FIGURE 4. Distribution of the transverse momentum with respect to the associated jet for pions and kaons in the b-depleted sample (left) and for muons in the b-enriched sample (right).

all the other contributions have been fixed. The previous OPAL measurement of open charm production [1] is used to fix the absolute contributions of open c production via the direct and single-resolved processes, where the shape is given by the PYTHIA Monte Carlo program. Most of the muons found in the uds background are due to decays of pions and kaons into muons, therefore the rate of pion and kaon production is measured separately. A b-depleted sample of photon-photon events is selected with $\mathcal{N}_\mu < 0.65$ and with pion and kaon identification using $\mathrm{d}E/\mathrm{d}x$ measurements. The transverse momentum relative to the jet axis for the charged hadrons in this b-depleted sample, $p^{\mathrm{h}}_{\mathrm{T,rel}}$, shown in Figure 4 (left), was used to find the scaling factor of 1.35 ± 0.03 for the PHOJET Monte Carlo cross-section.

The predictions for processes other than anti-tagged hadronic photon-photon interactions are taken entirely from Monte Carlo simulations. The fraction f_{BG} of background events is about 10%. The main contributions to this background are $\mathrm{e^+e^-}$annihilation events into hadrons (54%), deep inelastic electron-photon scattering events (29%), production of four fermions from other reactions than photon-photon scattering processes (9%) and τ pairs produced in photon-photon interactions (7%).

The final result of the one-parameter fit to the b-enriched sample, shown in Figure 4 (right), yields a beauty fraction $f_{\mathrm{b}} = (27.2 \pm 4.8\ (\mathrm{stat}))\%$ with $\chi^2 = 5.8$ (ndf=7), corresponding to 121 ± 21 events. The fraction of the other processes are approximately $f_{\mathrm{c}} = 24\%$, $f_{\mathrm{uds}} = 37\%$ and $f_{\mathrm{BG}} = 10\%$.

The cross-section $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-b\bar{b}})$ is determined from the measured number of events using the branching ratios of b hadrons into muons taken from [8]. The total open b cross-section is determined to be $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-b\bar{b}}) =$

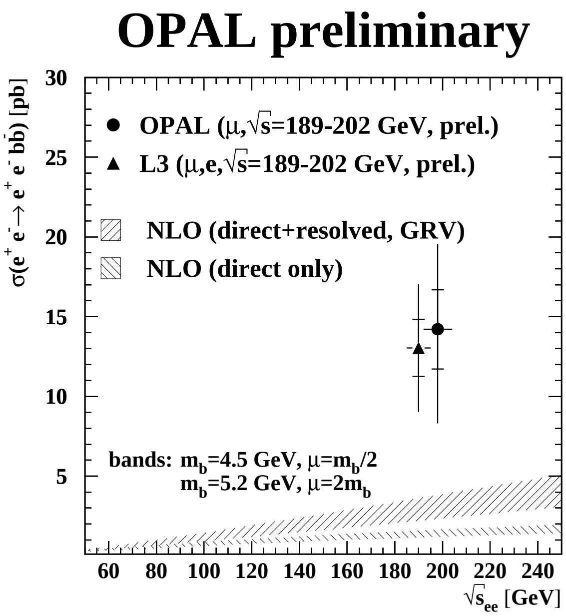


FIGURE 5. The total beauty production cross-section $\sigma(\mathrm{e^+e^-} \to \mathrm{e^+e^-b\bar{b}})$ measured in the range $\sqrt{s_{\mathrm{ee}}} = 189-202$ GeV compared to the preliminary L3 result and the prediction of an NLO calculation.

14.2 ± 2.5 (stat) $^{-4.8}_{+5.3}$ (sys) pb. The precision of the measurement is currently limited by the systematic errors associated with the background from charm production, but the improved charm measurement presented above will help to reduce this uncertainty.

Figure 5 shows the measured open b cross-section compared to the preliminary L3 result performed in the same $\sqrt{s_{\mathrm{ee}}}$ range using semileptonic decays of b hadrons into muons and electrons [9], and an NLO calculation that uses matrix elements for massive b quarks [5], with the direct contribution shown separately. The prediction of the NLO calculation for the total cross-section at $\sqrt{s_{\mathrm{ee}}} = 200$ GeV is 3.88 pb and 2.34 pb for a b quark mass of 4.5 GeV and 5.2 GeV, respectively, significantly lower than both measurements. A recent measurement of the open beauty cross-section in photon-proton collisions is also about 2.5 standard deviations higher than expected from an NLO calculation [10].

CONCLUSION

The inclusive production of $\mathrm{D}^{*\pm}$ mesons has been measured in anti-tagged photon-photon collisions using the OPAL detector at LEP. The contribution of the direct process in the kinematical region $p_{\mathrm{T}}^{\mathrm{D}^*} > 2$ GeV and $|\eta^{\mathrm{D}^*}| < 1.5$ is determined from the $x_{\mathrm{T}}^{\mathrm{D}^*}$ distribution to be $r_{\mathrm{dir}} = (44 \pm 6)\%$.

The measured differential cross-section as a function of the D^* transverse mo-

mentum and pseudorapidity is compared to NLO calculations using the massless and the massive approaches, and despite the low values of $p_{\mathrm{T}}^{\mathrm{D}^*}$ studied the massless calculation is in good agreement with the data, while the massive calculation underestimates them for lower values of $p_{\mathrm{T}}^{\mathrm{D}^*}$.

The cross-section of the anti-tagged $\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\mathrm{D}^* X$ process is measured in the restricted kinematical range of $p_{\mathrm{T}}^{\mathrm{D}^*} > 2$ GeV and $|\eta^{\mathrm{D}^*}| < 1.5$ to be $\sigma_{\mathrm{meas}}^{\mathrm{D}^*} = 30.7 \pm 2.8(\mathrm{stat}) \pm 3.3(\mathrm{syst})$ pb. The extrapolation of this result to the total charm cross-section introduces large uncertainties both on the theoretical and experimental side, therefore at present a comparison in the restricted kinematic range is preferred.

The open b cross-section in photon-photon events has been measured using the semi-leptonic decays of b hadrons into muons. The spectrum of the transverse momentum of the muons with respect to the closest jet axis is fitted after all background contributions have been fixed independently, leading to a measured total cross-section of $\sigma(\mathrm{e}^+\mathrm{e}^- \to \mathrm{e}^+\mathrm{e}^-\mathrm{b\bar{b}}) = 14.2 \pm 2.5$ (stat) ${}^{-4.8}_{+5.3}$ (sys) pb, in agreement with the preliminary L3 measurement. However, the NLO QCD calculation underestimates the measured total cross-section by about 2 standard deviations.

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